

EXPERIMENTS PERTAINING TO THE FORMATION AND EQUILIBRATION OF PLANETARY CORES

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I

High-Pressure Metallization of FeO and Implications for the Earth's Core Elise Knittle and Raymond Jeanloz

The phase diagram of FeO has been experimentally determined to pressures of 155 GPa and temperatures of 4000 K using shock-wave and diamond-cell techniques. We have discovered a metallic phase of FeO at pressures greater than 70 GPa and temperatures exceeding 1000 K. The metallization of FeO at high pressures implies that oxygen can be present as the light alloying element of the Earth's outer core, in accord with the geochemical predictions of Ringwood. The high pressures necessary for this metallization suggest that the core has acquired its composition well after the initial stages of the Earth's accretion. Direct experimental observations at elevated pressures and temperatures indicate that core-forming alloy can react chemically with oxides such as those forming the mantle. The core and mantle may never have reached complete chemical equilibrium, however. If this is the case, the core-mantle boundary is likely to be a zone of active chemical reactions.

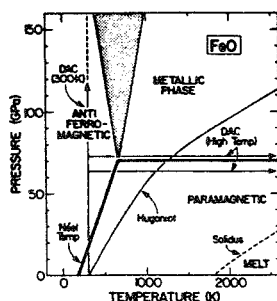


Figure 1. Phase diagram of FeO based on high-pressure experiments with the diamond cell (DAC) and by shock-wave techniques (Hugoniot). Diamond-cell experiments have been carried out both at room temperature (300 K) and at combined high temperatures and pressures, as indicated on the figure. The phase boundaries between antiferromagnetic (nonmetallic), paramagnetic (nonmetallic), and metallic phases are shown by heavy lines and a shaded region; the latter reflects the uncertainty in the slope of the boundary. The solidus is given by a dashed line.

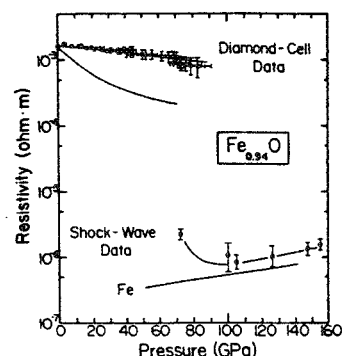


Figure 2. Room-temperature diamond-cell (0 to 83 GPa) and high-temperature shock-wave (72 to 155 GPa) electrical resistivity data for FeO. Shock-wave resistivity measurements for iron [Keeler and Mitchell, 1989] are summarized (solid line) to illustrate that the resistivity of FeO is metallic at elevated pressures and temperatures. The three order of magnitude difference in resistivity between the diamond-cell and shock-wave measurements at 80 GPa cannot be explained as a temperature effect on semiconducting FeO. The dashed line is the calculated resistivity for semiconducting FeO at high temperature. At 72 GPa and 1200 K (the calculated Hugoniot temperature) the predicted resistivity is still two orders of magnitude higher than that observed in the shock-wave experiments.

II

The Melting Curve of Iron to Over 100 GPa and of Iron Sulfide to Over 60 GPa Quentin Williams and Raymond Jeanloz

We have measured the melting curve of Fe and FeS to pressures exceeding 100 GPa and 60 GPa, respectively, using a laser-heated diamond cell. Temperatures of the samples were determined spectroradiometrically, and melting was determined based upon a combination of visual observation during heating and of textural observations on the quenched samples. To avoid chemical reaction with the diamond anvils, all samples were suspended in an Al_2O_3 (ruby) matrix. Our results for iron agree with previous measurements below 7 GPa, and indicate a melting temperature of 4100 (± 200) K at 100 GPa. By extrapolation, we find that the melting temperature of iron at the pressure of the core-mantle boundary (136 GPa) is 4500 (± 300) K. Our data for FeS suggest an initially steeply rising melting curve (temperature of 3000 K at 50 GPa), with greater curvature at high pressure than that observed for iron. We find no evidence for the hot iron samples reacting with the ruby when they are solid, but both molten Fe and molten FeS appear to react significantly with the oxide at elevated pressures.

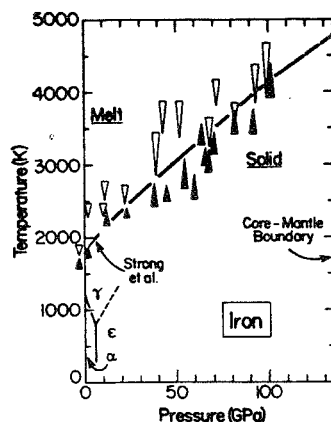


Figure 3. Bounds on the melting curve of iron from static experiments as a function of pressure. Solid triangles represent the highest temperature measured on solid iron samples at a given pressure, while open triangles indicate the lowest temperature of liquid samples. Lengths of symbols reflect the statistical uncertainty in temperature from the relevant spectral fit. The low-pressure melting curve of Strong et al. (2) is also shown, along with the phase equilibria of the known iron crystalline phases: α represents the body-centered-cubic structure, ϵ the hexagonal close-packed structure, and γ the face-centered cubic structure.